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Development of an Open-Education Resource Laboratory Manual for Digital Design Course

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Abstract

This study delineates the creation and efficacy of an innovative Open-Education Resource (OER) Digital Design Laboratory Manual in enhancing the educational outcomes of sophomore students in an Electrical and Computer Engineering Digital Design Laboratory course. The primary objectives of this study were threefold: to elevate the quality of students' learning experiences, to alleviate their financial constraints by offering complimentary course materials, and to ensure the adaptability of these resources in tandem with evolving technological advancements.

Traditionally, laboratory manuals, especially those tailored for specific engineering programs, are highly specialized. However, given the rapid evolution in the field of digital design, frequent updates to these manuals are imperative. The market offered several electronic versions of digital design lab manuals, but these predominantly focused either on discrete logic activities or Field-Programmable Logic Device (FPLD) board activities. Our curriculum required a synthesis of both. Furthermore, existing manuals were often constrained by their alignment with specific CAD software, development boards, and bench equipment, limiting their applicability.

Intel Inc., through its educational initiatives, offers complimentary resources primarily centered on FPLD board activities, catering to a more advanced demographic. This gap in available resources led to the development of our new OER lab manual, which was implemented in the Fall of 2022.

To gauge the success of this initiative, both qualitative and quantitative assessment methods were utilized. These evaluations aimed to establish benchmarks for the impact of the new material on students' academic performance and overall satisfaction. The findings indicate a notable enhancement in student performance and satisfaction levels among those who utilized the new lab manual, underscoring the efficacy of this innovative educational resource in the realm of digital design education.

Introduction

A significant development in this digital education era is the concept of Open Educational Resources (OERs). These resources are essentially teaching, learning, and research materials that are freely available in the digital sphere, often situated in the public domain or released under an open license [1]. The essence of an OER lies in its open nature, granting permission for free access, utilization, adaptation, and redistribution, thereby removing traditional barriers to educational resources. Research in the field suggests that students generally hold favorable attitudes and perceptions toward open educational resources, as evidenced in many studies, such as [2–5]. Therefore, the initiative documented in this paper centers on enhancing the pedagogical framework of the sophomore-level Electrical and Computer Engineering course, Digital Design Lab (ENGR 2323), at Georgia Southern University. The project's overarching aim was to revolutionize the student experience in this course by providing an enriched learning environment and alleviating financial burdens through the provision of cost-free educational materials.

Previously, the course utilized a lab manual [6] that was not optimally aligned with the specific lab equipment available. To address this discrepancy, we introduced a no-cost, tailor-made lab manual designed to align seamlessly with the development boards and bench equipment utilized in our labs. This manual integrates the use of cutting-edge CAD software and development boards, with the selected CAD software being freely accessible to students for extracurricular use. The newly developed Open-Education Resource (OER) materials are digitally available, encompassing written texts, lab assignments, and comprehensive tutorials—both written and multimedia—covering the software, development boards, and bench equipment. Additionally, these resources provide the flexibility for students to print materials as needed.

ENGR 2323, which is mandatory for Electrical and Computer Engineering majors, is offered in multiple sections across two campuses during the fall and spring semesters. The course, comprising 2 credit hours with 4 contact hours weekly, is the students' initial hardware-based laboratory experience, following the prerequisite course, Logic Circuit Design (ENGR 2332). It maintains uniformity in curriculum, content, textbooks, software, and learning outcomes across both campuses, with identical lab equipment at each location.

The course's inherent complexity, stemming from the use of CAD software, discrete logic, powered protoboards, FPLD development boards, and bench equipment like oscilloscopes and logic analyzers, often presents challenges to students. The newly developed resources aim to significantly enhance both the laboratory experience and academic performance of students. These resources include a comprehensive lab manual, augmented by detailed written and multimedia tutorials for the CAD software and laboratory equipment.

The impacts of this new OER lab manual are multifaceted, as listed below:

- Financially, it offers an estimated annual saving of $6,600 for the approximately 100 students enrolled each academic year, as the course materials are now available at no cost.
- The resources are tailored to meet the specific learning outcomes of the course.
- The resources are custom-designed for the CAD software and lab equipment used, enhancing practical applicability.
- The inclusion of interactive multimedia elements like videos fosters a more engaging and effective learning experience.
- With electronic resources readily available, students avoid delays in accessing textbooks, ensuring immediate access to all necessary resources from the onset of the lab sessions. This availability also enables students to review prerequisite course material efficiently.

- The electronic format allows for straightforward updates and maintenance, ensuring that the resources remain current with modern software, hardware, and digital design techniques.
- By enhancing this foundational laboratory course, we anticipate an increase in course completion rates, facilitating smoother progression for students in their degree programs.
- Given the commonality of similar courses across various institutions offering Electrical and Computer Engineering, these resources have the potential to benefit faculty and students in comparable academic settings.

OER Manual Development

Faculty members with extensive experience in teaching the designated course undertook a comprehensive review of the existing laboratory activities. Their objective was to refine the curriculum, and they successfully identified a range of seven to nine essential activities that encompass areas such as combinational circuit design, sequential circuit design, VHDL-based design, realization using discrete logic, and implementation with Field-Programmable Logic Devices (FPLDs). Additionally, further activities that delve into register transfer language (RTL) level design and aspects of computer architecture are being developed.

Intel's Quartus Prime Lite design software and the terasIC DE-10 Standard board were selected as the foundational platform for the development of the lab manual [7]. Recognizing the need for specificity in an introductory digital logic lab course, the team aimed to create resources that, while as general as possible, provide detailed guidance for the specific CAD software, development boards, and bench equipment used at our institution. The lab manual's major enhancements include detailed instructions for both pre-lab and in-lab activities, a succinct yet comprehensive conceptual background for each lab, and multimedia demonstrations of the design tools and lab equipment. Additionally, the online manual features a frequently asked questions section, addressing common challenges and pitfalls encountered by students during lab sessions.

To ensure inclusivity and accessibility, the team developed a disability-accessible template in Microsoft Word for all static materials. Responsibilities for the primary development of two to four labs were distributed among project team members, with each member creating background material that includes the necessary theory, design examples, and guides for both CAD software and FPLD boards. A single team member was tasked with the final editing process, ensuring consistency and coherence in style and content across the manual.

The instructional resources for each laboratory activity in our curriculum are carefully assembled to provide a comprehensive learning experience. These resources include a diverse array of materials tailored to enhance understanding and engagement in each lab session. For every laboratory activity, students are provided with:

1) Lab Activity Guide: A detailed PDF document outlining the objectives, procedures, and expected outcomes of the lab.

2) Lecture Slides: Supporting Microsoft PowerPoint presentations that offer an overview and essential theoretical concepts relevant to the lab.
3) Background Materials: A collection of PDF documents and MP4 videos that provide foundational knowledge and context, ensuring students are well-prepared for the lab exercises.
4) Help/Tutorial Materials: Instructional PDFs and MP4 videos offering step-by-step guidance and troubleshooting tips for lab-related software and equipment.

For instance, the "Introduction to Computer-Aided Design" laboratory activity (Lab 1) encompasses:

- A comprehensive lab activity guide.
- Informative lecture slides.
- Background materials on digital logic technologies.
- A suite of help documents and tutorials, including instructions on installing Quartus Prime, designing schematics in Quartus, FPLD board pin assignments, and programming the FPLD board. Accompanying videos for these Quartus help materials are currently being developed.

Similarly, the "Realizing Combinational Circuit using Discrete Logic" laboratory activity is equipped with analogous materials, supplemented by a helpful instructional video on constructing digital circuits on a solderless protoboard. These diverse and extensive resources are designed not only to guide students through the technical aspects of the lab activities but also to enrich their understanding of the underlying principles and real-world applications of the concepts taught.

The distribution of these lab materials to students is facilitated through a dedicated course website, ensuring easy and continuous access. In their initial semester of implementation, these resources were also made available through the university's learning management system, offering a complementary access point and reinforcing the commitment to provide comprehensive educational resources.

Course Website

In the realm of open educational resources (OER), the accessibility and relevance of materials are crucial. To address this, a dedicated website (https://sites.google.com/georgiasouthern.edu/digitaldesign) was developed using Google Sites, serving as a central hub for disseminating the OER materials related to the Digital Design course both to students and the broader OER community. This website is actively managed and regularly updated by the development team, ensuring that the content remains current, reflecting the latest advancements in software and hardware. Additionally, it allows for dynamic adaptation to align with the evolving learning objectives of the course.

The website's architecture is thoughtfully designed, featuring a main landing page that provides a succinct yet informative overview of the Digital Design OER materials. This page serves as a gateway, offering direct links to the various lab resources available. To facilitate ease of navigation and enhance user experience, a 'Lab Experiments' tab is prominently featured, allowing students to effortlessly transition to individual lab sections.

Figure 1 captures the main page of the course website, illustrating its layout and intuitive user interface. This visualization aids in conveying the website's structured design and how students can efficiently navigate through the available resources, seamlessly accessing the specific lab content they require. The integration of this web-based platform exemplifies the commitment to providing accessible, up-to-date educational resources, leveraging technology to enrich the learning experience in the field of digital design.

Figure 1. The Main Page of the Course Website

Figure 2 offers a detailed visualization of the webpage dedicated to Lab#1, exemplifying the design approach employed across all lab pages on the website. This illustration serves to showcase the deliberate and thoughtful design choices made in creating an online educational resource that is both functional and user-friendly.

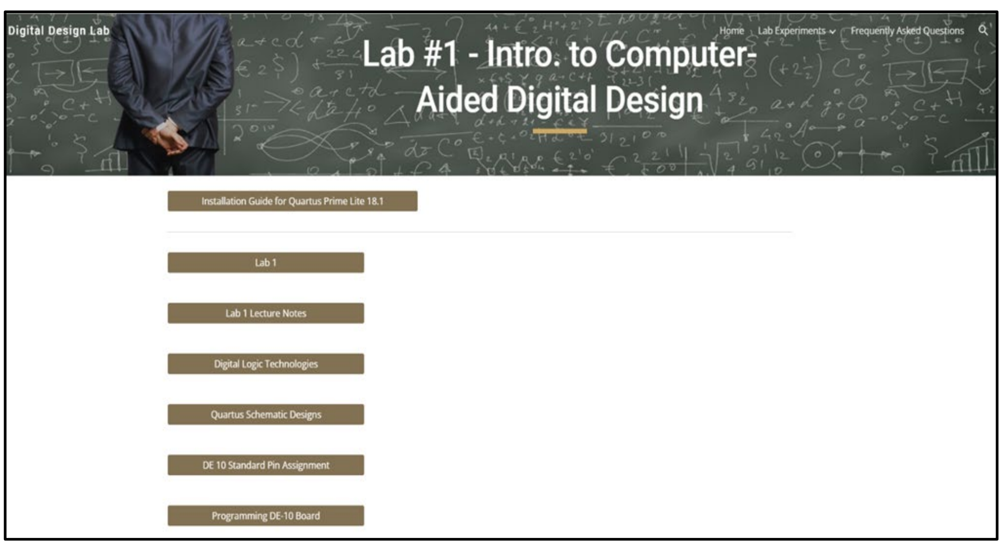

Figure 2. A Sample Lab Experiment Webpage for Lab#1.

The webpage for Lab#1, as depicted in Figure 2, is characterized by its minimalistic and streamlined design. This design philosophy has been adopted to prioritize ease of navigation and clarity, ensuring that users can effortlessly access and comprehend the lab content. The minimalistic format effectively eliminates any potential clutter or confusion, enabling students to focus on the essential elements of the lab without distraction.

This approach to webpage design is pivotal in enhancing the student experience. By providing a clear, well-organized, and intuitive interface, the website ensures that students can navigate through the lab materials with ease and efficiency. This design strategy, as illustrated through the Lab#1 webpage, reflects a deep understanding of the needs of the students and a commitment to delivering education content in the most accessible and effective manner.

Course Curriculum and Schedule

The course curriculum is thoughtfully structured to provide a comprehensive understanding of key concepts in digital design through hands-on laboratory experience. It comprises seven distinct lab activities, each designed to build upon the knowledge and skills acquired in the preceding labs. The lab activities include:

- **Lab 1: Introduction to Computer-Aided Design** - This lab introduces students to the fundamentals of digital design using computer-aided tools.
- **Lab 2: Combinational Circuit Design Using VHDL** - Students explore the design of combinational circuits using VHDL descriptions.
- **Lab 3: Combinational Circuit Realization Using Discrete Logic** - This lab focuses on the practical realization of combinational circuits using discrete logic components.
- **Lab 4: Digital Circuit Timing Using Oscilloscope** - Students learn to measure and analyze the timing aspects of digital circuits using an oscilloscope.
- **Lab 5: State Machines Design and Realization Using Discrete Logic** - This lab introduces the concept and design of state machines and their realization using discrete logic.
- **Lab 6: State Machine Design and Testing Using VHDL** - Students delve into the design and testing of state machines using VHDL.
- **Lab 7: Practical Application of State Machines** - The focus is on applying state machine concepts to practical digital design scenarios.

Each lab session is preceded by pre-lab activities that students are required to complete prior to the lab. These pre-labs are evaluated to provide constructive feedback and ensure students are adequately prepared for the lab exercises.

Additionally, the course culminates in a comprehensive final semester project spanning five weeks. In this project, student groups, consisting of three members, assigned randomly, are tasked with designing a more complex digital circuit that integrates the concepts and tools introduced throughout the course. At the semester's end, each group is required to present their project both orally and through practical demonstrations.

Given the course's significance as the first engineering course evaluated for ABET student learning outcomes (SLOs 1 through 7), a dedicated week is allocated to cover engineering ethics. This includes both lectures and activities designed to instill a strong ethical foundation in future engineering practices. The course schedule for the fall semester, detailing weekly activities and lab schedules, is outlined in Table 1. This schedule is structured to optimize learning outcomes and ensure a cohesive flow of course content.

Table 1. A Sample Course Schedule

Day/Date	Topics	Assignments
Week 1	Course Overview, Lab Equipment, and Safety	Install Altera Quartus
Week 2	Intel Quartus, Schematic Designs, Programming FPLDs	Lab 1 Prelab
	Lab 1	
Week 3	VHDL	Lab 2 Prelab
	Lab 2	Lab 1 Results
Week 4	Datasheets, Protoboards, Combinational Circuit Design, and Testing	Lab 3 Prelab
	Lab 3	Lab 2 Results
Week 5	Circuit Timing, Oscilloscope	Lab 4 Prelab
	Lab 4	Lab 3 Results
Week 6	Sequential Circuit Design and Testing	Lab 5 Prelab
	Lab 5	Lab 4 Results
Week 7	Sequential Circuit Design using VHDL, Automated Testing, Logic Analyzer	Lab 6 Prelab
	Lab 6	Lab 5 Results
Week 8	Counters, Timers, Seven Segment Display	Lab 7 Prelab
	Lab 7	Lab 6 Results
Week 9	Ethics	
	Ethics Homework Assignment	Lab 7 Results
Week 10	Design Project Proposal	
	Design Project Proposal	Ethics Homework
Week 11	Design Project	
	Design Project	Project proposal
Week 12	Written Exam	
	Practical Exam	Project Proposal
Weeks 13, 14, 15	Design Project	Design Project Status
	Design Project	
Week 16	Design Project	Presentation Draft
	Design Project Presentations	Design Project Report

Assessment of Implementation Impact

In Fall 2022 and Spring 2023, the implementation of new Open Educational Resources (OER) lab materials resulted in notably smoother lab experiences compared to the preceding year. Students encountered fewer difficulties and required less assistance when utilizing the lab equipment, Field-Programmable Logic Devices (FPLD) development boards, and design software than in previous semesters. Furthermore, students exhibited a higher completion rate of labs within the standard lab period. In contrast, prior to the adoption of these materials, students frequently needed more guidance in equipment usage, and it was commonplace for them to be unable to finish labs during the designated lab time, necessitating additional work outside of regular lab hours. This presented challenges as the lab facilities were typically inaccessible beyond their scheduled hours, and equipment availability was restricted to the lab environments.

The improved lab experience can be primarily attributed to the customization of lab materials to align with the specific needs of the students. Lab instructions were thoughtfully designed to address the common issues students typically encountered when working with the particular equipment featured in the labs. Essential lab materials, such as instructions and instructional videos, were tailored to the specific design software and lab equipment employed in the course.

One notable advantage of the electronic lab materials is their adaptability and ease of updating. These resources are actively maintained by the course coordinator and faculty members responsible for teaching the course regularly. Any faculty member involved can promptly rectify typographical errors, address ambiguities, or introduce additional materials to clarify topics that students find challenging or unclear. For instance, during the Fall 2022 semester, one of the authors taught the initial course section each week, enabling timely corrections of typos and the addition of supplemental materials before they were utilized by other sections. The decision to provide the materials in multiple smaller documents rather than a single comprehensive manual facilitates the seamless integration of supplementary content without disrupting the overall flow of the instructional materials.

To gauge the effectiveness of the new lab manual introduced in the ENGR 2323 course, we employed a normalized measure of performance. This approach was chosen to provide a more accurate reflection of the project's impact on student performance, considering the variability in student abilities and cohort differences across academic years. The chosen metric involved calculating the difference between a student's grade in the ENGR 2323 lab and their cumulative GPA. By using the cumulative GPA as a baseline for each student's general academic performance, we were able to assess how the lab performance compared to their overall academic standing. To account for the differing student numbers in academic years (AY) 2021-2022 and 2022-2023, we averaged these delta values for all students.

The analysis revealed that, on average, students experienced a 0.154-point out of 4-points (or 3.86%) improvement in their course grade with the new lab manual, compared to only a 0.089-point out of 4-points (or 2.25%) improvement using the old manual. This indicates a near doubling (~42% increase) in grade improvement with the implementation of the new manual.

The Drop/Fail/Withdrawal (DFW) rate for the AY 2022-2023 was 15%, aligning with our typical expectations. For context, the DFW rate for AY 2021-2022 was 13.4%. As the implementation of the new material matures and undergoes optimization, we anticipate further improvements in this rate. Additionally, student feedback collected during this period will be instrumental in refining the course content and enhancing the learning experience for future cohorts.

Qualitative surveys were conducted before (Spring 2022) and after the project's implementation to supplement the quantitative analysis. These surveys, aimed at capturing students' perceptions and satisfaction levels, were administered anonymously using Google Forms. Students were asked to rate their agreement with various statements on a scale from 1 (strongly disagree) to 5 (strongly agree), covering aspects such as their preparedness by previous courses, the clarity and usability of the lab manual, and the adequacy of lab time, as enumerated below:

- **Q.1** - Logic Circuit Design (ENGR 2332) prepared me for the concepts and work in the Digital Design Lab (ENGR 2323).
- **Q.2** - The current lab manual is easy to read and understand.
- **Q.3** - The background for the labs in the manual is clearly explained and easy to follow.
- **Q.4** - Completing the laboratory prelab work before lab helped me prepare for it.
- **Q.5** - The lab time is adequate for completing the labs.

Figure 3 summarizes the survey results, which show a marked improvement in student satisfaction with the new lab model. Notably, over 76% of students agreed that the new lab manual was easy to read and understand, compared to only 16.67% for the old manual. About 81% felt that the lab background was clearly explained and easy to follow, a significant increase from 33.33% with the old manual. Additionally, approximately 86% agreed that completing the pre-lab work with the new manual better prepared them for the lab, a substantial improvement from 16.67%. Also, 86% of students felt that the allocated lab time was adequate using the new manual, compared to only 16.67% previously.

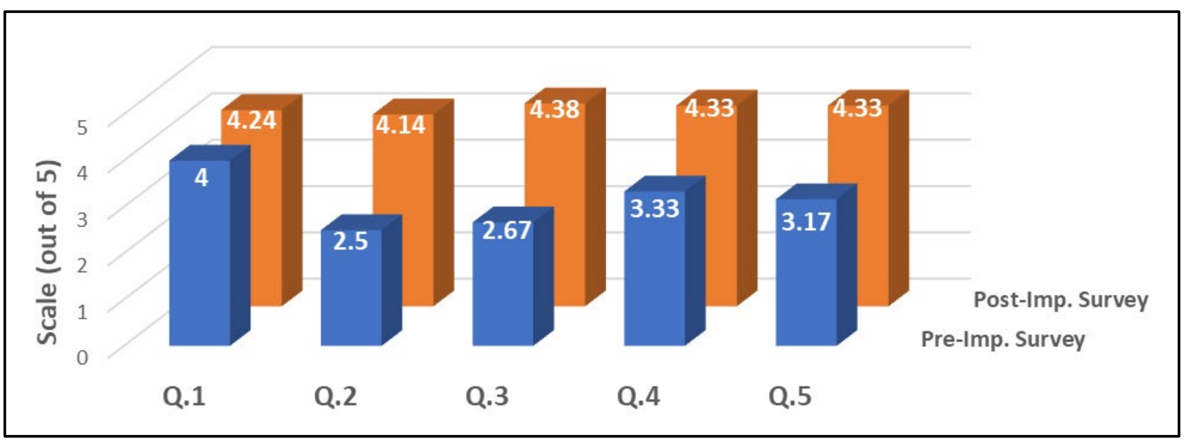

Figure 3: Assessment Results for Pre and Post-Implementation Surveys.

To comprehensively assess the effectiveness of the lab manuals, both old and new, we incorporated open-ended questions into our student surveys. These questions were designed to elicit detailed feedback and reflections based on the students' experiences with the lab activities. The questions focused on three key areas:

1) **Time Investment**: Students were asked to estimate the number of hours they spent weekly on pre-lab work, completing the lab, and writing lab reports.
2) **Manual Organization**: Opinions were solicited on the organization of the labs in the lab manual.
3) **Areas for Improvement**: Students were encouraged to suggest improvements to the current lab manual.

Feedback for the Old Lab Manual

- **Time Investment (Q.1)**: Responses indicated that students felt the workload was excessive for a 2 credit-hour course.
- **Manual Organization (Q.2)**: Some found the lab manual lengthy but not difficult to follow, though balancing time with other courses was challenging. Others noted confusion due to additional materials provided alongside the manual.
- **Areas for Improvement (Q.3)**: Feedback highlighted confusion in navigating the manual, particularly with unclear instructions on software tool usage. Simplification was suggested for ease of understanding.

Feedback for the new Lab Manual

- **Time Investment (Q.1)**: The reported time spent was around 4-5 hours per week, indicating a more manageable workload.
- **Manual Organization (Q.2)**: Students praised the new manual for its organization, ease of following, and clarity in objectives.
- **Areas for Improvement (Q.3)**: While many found the new manual satisfactory as is, suggestions included more precise labeling of lab folders on the course platform for easier access and additional VHDL practice labs for better course preparation.

These insights from students offer valuable perspectives on both versions of the lab manual. While the new manual has been well-received for its improved organization and clarity, the feedback also presents opportunities for further refinements to enhance the learning experience.

Conclusion

The comprehensive redesign of the Digital Design Lab course (ENGR 2323) at Georgia Southern University, as detailed in this paper, represents a significant stride in enhancing the educational framework for sophomore-level Electrical and Computer Engineering students. The project's primary objectives were to revolutionize the student learning experience and reduce financial burdens, both of which were successfully achieved through the development and implementation of a tailor-made, open-educational resource (OER) lab manual.

This new lab manual, aligned with the latest CAD software and lab equipment, has not only improved the practical applicability of course materials but also contributed to a more engaging and effective learning experience through the inclusion of interactive multimedia elements. The electronic format of these resources facilitated immediate and continuous access, allowing for more efficient learning and preparation.

Quantitative assessments indicate a significant improvement in student performance, as evidenced by the increase in course grades and consistent DFW rates. Qualitative feedback gathered through student surveys further underscores the effectiveness of the new lab manual. The increase in student satisfaction with the manual's readability, organization, and clarity in objectives highlights the success of this initiative. Additionally, the constructive feedback obtained provides a roadmap for continuous improvement and refinement of the course materials.

The course's growing enrollment and the consequent expansion in faculty participation attest to the rising interest and relevance of this program. The structured approach to course curriculum and scheduling, coupled with the dynamic and responsive nature of the course materials, ensures that the Digital Design Lab course remains at the forefront of engineering education.

Furthermore, the course's alignment with ABET student learning outcomes and the incorporation of engineering ethics emphasize the department's commitment to not only technical proficiency but also ethical awareness among its students.

In conclusion, the transformation of the Digital Design Lab course at Georgia Southern University stands as a testament to the potential of thoughtfully designed educational resources to enhance student learning outcomes. The ongoing process of assessment and refinement ensures that the course will continue to evolve, keeping pace with technological advancements and educational best practices. This initiative not only benefits the students of Georgia Southern University but also holds the promise of influencing digital design education in a broader academic context.

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